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Environmental Implementation Guide for Radiological Survey Procedures

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Prepared by the
Measurement Application and Development Group
of the
Health Sciences Research Division
of
Oak Ridge National Laboratory

5. RADIATION DETECTORS AND INSTRUMENTATION

Radiological surveys will typically require the collection of two types of radiological data: (1) direct field measurements using portable instruments and (2) sample analyses using fixed laboratory equipment or systems. For either type of measurement, the selection and proper use of appropriate instruments will likely be the most critical factors in assuring that the survey accurately determines the radiological status of the site. Radiological instrumentation consists of two components—a radiation detector and the electronic equipment needed to provide the power to the detector and to display or record the radiation events. This section identifies and very briefly describes the types of radiation detectors and associated display or recording equipment that are applicable to survey activities. Guidance for instrument application and use is provided in this section. Additional information on laboratory procedures using instrumentation described here is available in Sect. 6.

5.1 RADIATION DETECTORS

Radiation detectors can be divided into three general categories based on the detector material with which radiation interacts to produce a measured event. These categories are listed below. The particular capabilities of a radiation detector will establish its potential applications in conducting a specific type of survey. Lists of radiation detectors along with their usual applications to surveys are provided in Tables 5 .1 through 5.3.

- Gas-Filled Detectors

Radiation interacts with the detector, producing ion pairs in the filling gas that are collected by charged electrodes. Gas-filled detectors are usually categorized as ionization, proportional, or Geiger-Mueller (GM), referring to the region of gas amplification in which they are operated.

- Scintillation Detectors

Radiation interacts with a solid or liquid medium resulting in a small flash of light (known as a scintillation), which is converted to an electrical signal by a phototransducer.

- Solid-State Detectors

Radiation interacts with a semi-conductor material creating free electrons that are collected by a charged electrode. The design and the conditions under which a specific detector is operated determine the types of radiations (alpha, beta, and/or gamma) that can be measured, the detection level of the measurements, and the ability of the detector both to differentiate between different types of radiations and to resolve the energies of the interacting radiations. High-resolution detectors are constructed of either germanium or silicon and cooled to liquid nitrogen temperatures. Low-resolution models, which operate at room temperatures, have been constructed of various semi-conductor materials with the most common being cadmium telluride (CdZnTe).

Table 5.1. Radiation detectors with applications to alpha surveys[a]

Detector type	Detector description	Application
Gas proportional	<1 mg/cm^2 window; probe area 50 to 1000 cm^2	Surface scanning; surface contamination measurement
–	<0.1 mg/cm^2 window; probe area 10 to 20 cm^2	Laboratory measurement of water, air, and smear samples
–	No window (internal proportional)	Laboratory measurement of water, air, and smear samples
Air proportional	<1 mg/cm^2 window; probe area ~50 cm	Useful in low humidity conditions
Scintillation	ZnS(Ag) scintillator; probe area 50 to 100 cm^2	Surface contamination measurements, smears
–	ZnS(Ag) scintillator; probe area 10 to 20 cm^2	Laboratory measurement of water, air, and smear samples
–	Liquid scintillation cocktail containing sample	Laboratory analysis, spectrometry capabilities
Solid state	Silicon surface barrier detector	Laboratory analysis by alpha spectrometry

[a]Indicates number of progeny series measured to determine activity level of parent radionuclide of primary interest.

Table 5.2. Radiation detectors with applications to beta surveys[a]

Detector type	Detector description	Application	Remarks
Gas proportional	<1 mg/cm^2 window; probe face area 50 to 1000 cm^2	Surface scanning; surface contamination measurement	–
–	<0.1 mg/cm^2 window; probe area 10 to 20 cm^2	Laboratory measurement of water, air, smear, and other samples	–
–	No window (internal proportional)	Laboratory measurement of water, air, and smear samples	Can be used for measuring very low-energy betas
Ionization (non-pressurized)	1-7 mg/cm^2 window	Contamination measurement; skin dose rate estimates	–
Geiger-Mueller	<2 mg/cm^2 window; probe area 10 to 100 cm^2	Surface scanning; surface contamination measurements; laboratory measurement of samples	–
–	Various window thicknesses; few cm^2 probe face	Special scanning applications	–
Scintillation	Liquid scintillation cocktail containing sample	Laboratory analysis, spectrometry capabilities	–
–	Plastic scintillator	Contamination measurements	–

[a]It is recognized that the continual development of new technology will result in repeated changes in this listing.

Table 5.3. Radiation detectors with applications to gamma surveys[a]

Detector type	Detector description	Application	Remarks
Gas ionization	Pressurized ionization chamber; Non-pressurized ionization chamber	Exposure rate measurements	–
Geiger-Mueller	Pancake (<2 mg/cm^2 window) or side widow (~30mg/cm^2)	Surface scanning; exposure rate correlation when energy compensating shields are used.	Low relative sensitivity to gamma radiation
Scintillation	NaI scintillator; up to 5×5 cm	Surface scanning; exposure rate correlation	Cross-calibrate with pressurized ionization chamber (or equivalent) or for specific site gamma energy mixture for exposure rate measurements; high sensitivity
–	NaI scintillator; large volume and "well" configurations	Laboratory gamma spectrometry	–
–	CsI or NaI scintillator; thin crystal	Scanning; low-energy gamma and x-rays	Detection of low-energy radiation
–	Organic tissue equivalent (plastics)	Dose equivalent rate measurements	–
Solid state	Germanium semiconductor	Laboratory and field gamma spectrometry and spectroscopy	–

[a]It is recognized that the continual development of new technology will result in repeated changes in this listing.

5.2 DISPLAY AND RECORDING EQUIPMENT

Radiation detectors are connected to some type of electronic device to (1) provide a source of power for detector operation and (2) enable measurement of the quantity and / or quality of the radiation interactions that are occurring in the detector. The most common recording or display device used for radiation measurement is a ratemeter. A ratemeter provides a display on an analog meter, representative of the number of events occurring over some time period (e.g., counts per minute).

The number of events can also be accumulated over a preset time period using a digital scaling device. The resulting information from the scaling device is the total number of events over a fixed period of time, whereas a ratemeter display will vary with time. Also, determining the average level on a ratemeter will require a judgment by the user, especially when a low frequency of events results in significant variations in the meter reading.

Pulse height analyzers are specialized electronic devices designed to measure and record the number of pulses or events that occur at different pulse height levels. These types of devices are only useful when used with detectors which produce output pulses that are proportional in height to the energy deposited within them by the interacting radiation. They can be used to record only those events occurring in a detector within a single band of energy or can simultaneously record the events in multiple energy ranges. In the former case, the equipment is known as a single-channel analyzer; the latter application is referred to as a multichannel analyzer.

5.3 DETECTION SENSITIVITY

The detection sensitivity of a measurement system refers to a radiation level or quantity of radioactive material that can be measured or detected with some known or estimated level of confidence. This quantity is a factor of both the instrumentation and the technique or procedure being used. Two techniques of interest when performing radiological investigations are static measurements (i.e., direct measurements and laboratory analyses) and scanning surveys. After a measurement has been made, it is often desirable to calculate the uncertainty associated with the result.

The primary parameters that affect the detection capability of a radiation detector are the background count rate, the detection efficiency of the detector, and the counting time interval. It is important to use real background count-rate values and detection efficiencies when determining counting and scanning parameters, particularly during final status and verification surveys. When making field measurements, the detection sensitivity will usually be less than the value that can be achieved in a laboratory due to increased background and, frequently, a lower detection efficiency. Furthermore, it will often be impossible to guarantee that pure alpha emitters can be detected at all *in situ* since the weathering of aged surfaces or layers of absorbent materials such as dust and paint will often completely absorb the alpha emissions. NUREG-1507 (NRC 1995) contains data on many of the parameters that affect detection efficiencies *in situ*, such as absorption, surface smoothness, and particulate radiation energy.

5.3.1 Static Counting Sensitivity

Prior to analyzing samples or performing field measurements, an investigator must evaluate the detection sensitivity of the equipment being used to ensure that levels below the cleanup guideline can be detected (see Sect. 4.6). After a measurement has been made, it is then necessary to determine whether or not the result can be distinguished from the background response of the measurement system. The terms that are used in this manual to define detection sensitivity for fixed point counts and sample analyses are:

Critical level	(L_C)
Detection limit	(L_D)
Minimum detectable activity	(MDA)

The critical level (L_C) is the level, in counts, at which there is a statistical probability (with a predetermined confidence) of incorrectly identifying a background value as "greater than background." Any response above this level is considered to be greater than background. The detection limit (L_D) is an *a priori* estimated detection capability also in units of counts. The minimum detectable activity (MDA) is the detection limit (counts) multiplied by an appropriate conversion factor to give units consistent with a site guideline such as dpm or Bq/kg.

The following discussion provides an overview of the derivation contained in a well-known publication by L. A. Currie (1968) followed by a description of how the resulting formulae should be used. That publication by Currie and an earlier publication by Altshular and Pasternack (1963) provide details of the derivations involved for those who are interested.

The two parameters of interest for a detector system with a background response greater than zero are:

L_C The net response level, in counts, at which the detector output can be considered "above background."

L_D The net response level, in counts, that can be expected to be seen with a detector with a fixed level of certainty.

Assuming that a system has a background response and that random uncertainties and systematic uncertainties are accounted for separately, these parameters can be calculated using Poisson statistics. For these calculations, two types of statistical counting uncertainties must be considered. A Type I error (or "false positive") occurs when a detector response is considered to be above background when, in fact, only background radiation is present. A Type II error (or "false negative") occurs when a detector response is considered to be background when in fact above-background radiation is present. The probability of a Type I error is referred to as α (alpha) and is associated with L_C; the probability of a Type II error is referred to as β (beta) and is associated with L_D. Figure 5.1 graphically illustrates the relationship of these terms with respect to each other and to a normal background distribution.

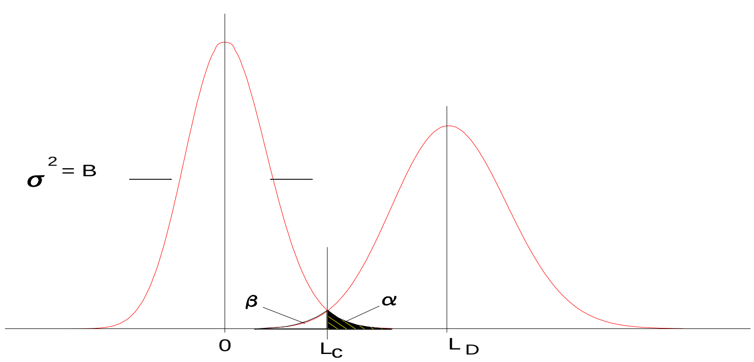
If α and β are assumed to be equal, and the variance (σ^2) of all measurement values are assumed to be equal to the values themselves, and the background of the detection system is not well known, then the critical detection level and the detection limit can be calculated by using the following formulae:

$$L_C = k\sqrt{2B}$$
$$L_D = k^2 + 2k\sqrt{2B} \qquad (5.1)$$

where

L_C = critical detection level (counts),
L_D = *a priori* detection limit (counts),
k = poisson probability sum for α and β (assuming α and β are equal),
B = number of background counts that are expected to occur while performing an actual measurement.

Referring to Fig. 5.1, the curve to the left of the diagram is the background distribution minus the background distribution. The result is a Poisson distribution with a mean equal to zero and a variance, σ_β^2, equal to B. Please note that the distribution accounts only for the expected statistical variation due to the stochastic nature of radioactive decay. For field-type measurements, it is expected that the background will vary significantly from point to point throughout a survey unit. In most cases, this variation will dominate the true shape of the background distribution. For this reason, it is important that realistic background values be used when performing calculations.



B = Background counts (mean)
L_C = Critical detection level (net counts)
L_D = Detection limit (net counts)
β = Probability of Type I error
α = Probability of Type II error

Figure 5.1 Graphically represented probabilities for Type I and Type II errors in detection sensitivity for instrumentation with a background response.

Currie assumed "paired blanks" when deriving the above-stated relationships, which is interpreted to mean that the sample and background count times are the same. Common practice, however, is to perform background counts for a longer period of time than the sample count and then to normalize the background response back to the sample count time. For example, if the background in 10 min is 20 counts and the samples are to be counted for 1-min, then the expected background during the sample count would be 2 counts.

If 5% false positives (Type I) and 5% false negatives (Type II) are selected to be acceptable levels for both types of errors, then k = 1.645 and the above equations can be written as:*

$$L_C = 2.32\sqrt{B} \qquad (5.2)$$
$$L_D = 3 + 4.65\sqrt{B}$$

Note: In Currie's derivation, the constant factor of 3 in the L_D formula was stated as being 2.71, but since that time it has been shown (Brodsky and Gallagher, 1991) and generally accepted that a constant factor of 3 is appropriate.

As part of the derivation of Eq. (5.2), it is assumed that the background response has some level of uncertainty associated with it. This uncertainty is subsequently propagated into the resulting formulae. If the background is very well known, then the uncertainty associated with the background response goes to zero and the equations become:

$$L_C = 1.645\sqrt{B} \qquad (5.3)$$
$$L_D = 3 + 3.29\sqrt{B}$$

The background response is usually well known in instruments that are used in a laboratory, whether they be of the mobile or the permanent location type. Background levels are more variable in field situations, and for practical application it should be assumed that the background is NOT well known, since in reality it will vary from point to point. In fact, the variation from point to point across a survey area may be very large when compared to the simple square root of the background, as shown in Eqs. (5.2) and (5.3). In cases such as these, it is recommended that a value for the background be selected from the upper 90% to 95% of the expected background values. By selecting a background from the high end of the expected distribution, one can ensure that the detection sensitivity is not underestimated and is, in fact, more realistic.

For an integrated measurement over a preset time, the minimum detectable activity (MDA) for a surface activity measurement is derived from Eq. (5.2) giving:

$$MDA = \frac{3 + 4.65\sqrt{B_R t}}{t \bullet E \bullet A \bullet C} \qquad (5.4)$$

where

MDA = minimum detectable activity [background NOT well-known, field measurements],
B_R = background in counts / minute,
t = counting time in minutes,
E = detector efficiency in counts / disintegration,

*The use of a false positive and false negative error rate of 5% is presented here and is recommended for general use. Alternate error levels may be selected (Currie 1968) when deemed necessary. In particular, the *in situ* measurement of some low risk isotopes such as ^{129}I and ^{14}C at current Appendix A guideline levels may not be plausible at 5% error levels. For conditions such as this, higher error levels may be selected and used in conjunction with process knowledge, swipes and/or samples to demonstrate compliance.

A = probe area correction factor (when needed),
C = other constants and factors when needed.

As for L_D, when the background is very well known and unchanging, the constant of 4.65 in Eq. (5.4) is replaced with a constant value of 3.29. In addition, other factors may be introduced into the calculation for estimating detection sensitivities for laboratory analyses. Examples of such factors are chemical recovery, sample size, and emission abundances for specific radiations of interest in the analytical process. An example of a calculation for a typical lab procedure for soil analysis would be:

$$MDA = \frac{3 + 3.29\sqrt{B_R\, t}}{t \bullet E \bullet S \bullet C} \tag{5.5}$$

where

MDA = activity per unit mass (Bq/g) [background well-known, laboratory measurements],
B_R = background rate in counts/second,
t = counting time in seconds,
E = detector efficiency in counts/disintegration,
S = sample size in grams,
C = other constants and factors when needed such as chemical recovery fraction.

The detection efficiency, E, and/or the other constants or factors represented by the variable C, are not necessarily true constants as shown in Eqs. (5.4) and (5.5). It is likely that at least one of these factors will have a certain amount of variability associated with it which may or may not be significant. For discussion purposes, suppose that these varying factors are gathered together into a single constant, k, by which the net count result will be multiplied when converting the final data. If k varies significantly between measurements, then one can select a value of k from the observed distribution of k values that represents a conservative estimate. Using this approach, a value of k would be selected that assures that at least 90% to 95% of the possible values of k are greater than the chosen value. The final calculated MDA is therefore assured of being at the upper 90th to 95th percentile of the distribution of possible MDA values, and a higher value of the MDA will result than would have been obtained had an average value of k been used. This approach for including uncertainties into the MDA calculation is recommended in both NUREG/CR-4007 (NRC 1994) and Appendix A to ANSI N13.30 (ANSI 1989). Practically speaking, when the source of variation in a conversion parameter influences the calculated MDA by only a small amount, then using an average value is certainly adequate. When variation in a parameter produces a large change in the final calculated MDA, then a conservative value should be selected.

Summary of Static Detector Sensitivity Terms

- The minimum detectable activity (MDA) is the *a priori* (i.e., before the fact) activity level that an instrument can be expected to detect 95% of the time. When stating the detection capability of an instrument, this value should be used. The MDA is the detection limit, L_D, multiplied by an appropriate conversion factor to give units of activity. Again, this value is used before any measurements are made to estimate the level of activity that can be detected using a given protocol.

- The critical detection level, L_C, is the lower bound on the 95% detection interval defined for L_D and is the level at which there is a 5% chance of calling a background value "greater than background" when, in fact, it is equal to background. This value should be used when actually counting samples or making direct radiation measurements. Any response above this level should be considered as above background; i.e., a net positive result. This will ensure 95% detection capability for L_D.

- Recognizing that *a priori* MDA values are used to evaluate the detection capability of instrumentation, it is more conservative to overestimate the MDA than to underestimate it for a given measurement method. When calculating MDA values, background estimates should be selected that represent the high end of what is expected. For field surveys, probes will be moved from point to point and, as a result, it is expected that the background will likely vary significantly due to variations in natural background source materials and variations in geometry and shielding. Ideally, the MDA values could be calculated for each type of area, but it will usually be more reasonable to select a single background value for a given surface type and use this result for planning survey activities. For similar reasons, conservative values of detection efficiencies and other process parameters should be used when the expected variations are significant. To a great degree, the selection of these parameters will be based on judgement and will require evaluation of site specific conditions. Please note that this approach is being recommended for calculation of *a priori* MDA values and is not being recommended for calculations of activity. When actually calculating net activity values, median, or average background values and detection efficiencies should be used.

MDA values for other counting conditions may be derived from Eq. (5.2) depending on the detector and contaminants of concern. For example, it may be required to determine what level of contamination distributed over 100 cm^2 can be detected with a 500-cm^2 probe or what contamination level can be detected with any probe when the contamination area is smaller than the probe active area. Table 5.4 lists several common field survey detectors with estimates of ideal MDA values for processed ^{238}U. Calculated results [using Eqs. (5.2) and (5.4)] are for static 1-min counts for processed ^{238}U when the background is NOT well known.

<u>Sample Calculation 1</u>

The following example is for determining the detection sensitivity at a 95% confidence level and assumes that the background is not well known [using Eq. (5.4)].

B_R = 40 counts / min,
t = 1 min,
E = 0.20 counts / disintegration,
A = 15 cm^2,
C = 60 dpm / Bq,

$$MDA = \frac{3 + 4.65\sqrt{40 \bullet 1}}{1 \bullet 0.2 \bullet \frac{15}{100} \bullet 60} ,$$

MDA = 18 becquerel / cm^2 [1080 dpm / 100 cm^2].

The critical level, L_C, for this example would be:

$$L_c = 2.32 \sqrt{40 \text{ H } 1} = 15 \text{ counts}$$

Table 5.4 Examples of estimated detection sensitivities for alpha and beta survey instrumentation

Detector	Probe area (cm^2)	Background (cpm)	Efficiency (cpm/dpm)	Approximate sensitivity L_C (counts)	L_D (counts)	MDA (dpm/100 cm^2)[a]
Alpha proportional	50	1	0.15	2	7	90
Alpha proportional	100	1	0.15	2	7	50
Alpha proportional	600	5	0.15	5	13	20
Alpha scintillation	50	1	0.15	2	7	90
Beta proportional	100	300	0.20	40	83	400
Beta proportional	600	1500	0.20	90	183	200
Beta GM pancake	15	40	0.20	15	32	1000

[a] Assumes that the size of the contamination area is 100 cm^2 with the exception of probes with face areas greater than 100 cm^2. In these cases, it is assumed that the size of the contamination is greater than the probe area. All MDA values have been rounded to one significant digit.

Given the above scenario, if a person asked what level of contamination could be detected 95% of the time using this method, the answer would be 18 Bq/cm^2. When actually performing measurements using this method, any count yielding greater than 55 total counts, or greater than 15 net counts, would be regarded as greater than background.

Sample Calculation 2

This example is for the laboratory analysis of a soil sample and assumes that the background is well known Eq. (5.5).

B_R = 2 counts/minute,
t = 30 minutes,
E = 0.02 counts/disintegration for nuclide of interest,
S = 750 grams,
C = 60 dpm/Bq • 1 kg/1000 g • 0.25 (chemical recovery yield),

$$\text{MDA} = \frac{3 + 3.2\sqrt{2 \cdot 30}}{30 \cdot 0.02 \cdot 750 \cdot \frac{60}{1000} \cdot 0.25} ,$$

$$= 4.1 \text{ Bq/kg } (1.1 \times 10^{-1} \text{ pCi/g}) \quad .$$

For demonstration of the effect of random uncertainty in counting parameters, assume that the chemical recovery yield used in this sample calculation has a 95% uncertainty bound of ± 0.03. What MDA value would represent the upper 95% bound (i.e., the highest value) of the expected distribution of MDA values (assuming the only random uncertainty other than counting statistics is caused by the variation in the chemical recovery)? The use of a lower recovery value will result in an increase in the calculated MDA, therefore the 95% uncertainty value should be subtracted from the mean value and used in place of the mean:

$$MDA_{95\%} = \frac{3 + 3.2\sqrt{2 \bullet 30}}{30 \bullet 0.02 \bullet 750 \bullet \dfrac{60}{1000} \bullet (0.25 - 0.03)}$$

$$= 4.7 \text{ Bq/kg } (1.3 \times 10^{-1} \text{ pCi/g})$$

As mentioned earlier, professional judgement should be used when choosing to evaluate uncertainty effects such as this.

5.3.2 Scanning Sensitivity

The ability to identify a small region or area of slightly elevated radiation during surface scanning is dependent upon the surveyor’s skill in recognizing an increase in the audible output of an instrument. For notation purposes, the term "scanning sensitivity" is used throughout this section to describe the ability of a surveyor to detect a predetermined level of contamination with a detector. The greater the sensitivity, the lower the level of the contaminant that can be seen.

Many of the radiological instruments and monitoring techniques typically used for applied health physics activities may not provide the detection sensitivities necessary to demonstrate compliance with the unrestricted release cleanup guidelines. The detection sensitivity for a given application can be improved (i.e., one may lower the MDA) by: (1) selecting an instrument with a higher detection efficiency or a lower background, (2) decreasing the scanning speed, or (3) increasing the size of the effective probe area without significantly increasing the background response.

Scanning is usually performed during radiological surveys in support of decommissioning to identify the presence of any locations of elevated direct radiation. The probability of detecting residual contamination in the field depends not only on the sensitivity of the survey instrumentation when used in the scanning mode of operation, but is also affected by the surveyor’s ability (i.e., human factors). The surveyor must make a decision as to whether the signals represent only the background activity or residual contamination in excess of background. The greater the sensitivity, the lower the level of contamination that may be detected by scanning.

5.3.2.1 Scanning for beta and gamma emitters

The background response of typical beta and gamma detectors can range from around 30 cpm to a few thousand cpm. Because the background event rate is significant, the ability of a person performing a radiation scan to detect a given level of contamination is difficult to evaluate. For beta and gamma surveys at near background levels, the audio output from a detection system will be the primary sensory input that a surveyor relies upon. Unfortunately, an individual's ability to evaluate this input is not a constant (i.e., it is affected by human factors, time of day, etc.) and is therefore not easily modeled or predicted. Even so, the ability of a human to evaluate patterns of "clicks" and to notice changes in those patterns is superior to that which can be accomplished with current digital technology.

At high background count rates, the surveyor will depend more on relative increases in the count rate (i.e., the rate of change and magnitude of the change) to determine whether or not a source of radiation above background is present. This is the usual scenario for most NaI survey systems with backgrounds on the order of 2000 to 3000 cpm and large-area beta proportional detectors with background responses near 1000 to 1500 cpm.

In the presence of background on the order of 30 to a few hundred cpm, as is the case with many gas-filled detectors, the count-rate level that will be distinguished as being *greater than background* will be based more on a surveyor's ability to distinguish a source plus background *click pattern* from a background *click pattern*. For example, if the background audio pattern for a one-second interval while passing over 1 detector width is normally

"click.......click...click............click",

then a pattern similar to

"click..click.click..click................"

while passing over the same distance may cause a surveyor to notice an increase and therefore stop to investigate. Although the number of counts occurring during the latter case was equivalent to the first, the pattern change would be recognizably different. Depending on how often the surveyor expected to hear the second pattern at a background location, the surveyor may or may not decide to call the chain of events "significant."

A practical method for evaluating the detection sensitivity for beta and gamma surveys is by actual experimentation or, since it is certainly feasible, by simulating an experimental setup by using computer software. The following steps provide a simple example of how one can perform this evaluation:

1. A desired nuclide contamination level is selected.
2. The response of the detector to be used is determined for the selected nuclide contamination level.
3. A test source is constructed which will give a detector count rate equivalent to that which was determined in Step 2. The count rate is equivalent to that which would be expected to be seen with the detector when placed on an actual contamination area equal in value to that selected in Step 1.
4. The detector(s) of choice is then moved over the source at different scan rates until an acceptable speed is determined.

The most useful aspect of this approach is that the source can then be used to show surveyors what level of contamination is expected to be targeted with the scan. They, in turn, can learn to recognize the expected response of the detector under differing circumstances and how fast they can survey while maintaining some level of comfort in detecting the target contamination level. The person responsible for the survey can then use this information when developing a fixed point measurement and sampling plan.

5.3.2.2 Scanning for Alpha Emitters

Scanning for alpha emitters differs significantly from scanning for beta and gamma emitters in that the expected background response of most alpha detectors is very close to zero. The following discussion covers scanning for alpha emitters and assumes that the surface being surveyed is similar in nature to the material on which the detector was calibrated. In this respect, the approach is purely theoretical. Surveying surfaces which are dirty, non-planar, or weathered can significantly affect the detection efficiency and therefore bias the expected MDA for the scan. The use of reasonable detection efficiency values is recommended. Appendix C contains a complete derivation of the alpha scanning equations used in this section. Section 4.3 contains information on performing radiation measurements for alpha emitters.

Since the time a contaminated area is under the probe varies and the background count rate of some alpha instruments is less than 1 cpm, it is not practical to determine a fixed MDA for scanning. Instead, it is more useful to determine the probability of detecting an area of contamination at a predetermined cleanup guideline for given scan rates and detector parameters.

For alpha survey instrumentation with backgrounds ranging from <1 to 3 cpm, a single count provides a surveyor sufficient cause to stop and investigate further. Assuming this to be true, the probability of detecting given levels of alpha surface contamination can be calculated by use of Poisson summation statistics. Given a known scan rate and a surface contamination cleanup guideline, the probability of detecting a single count while passing over the contaminated area is:

$$P(n \geq 1) = 1 - e^{\frac{-GEd}{60v}} \tag{5.6}$$

where

$P(n \geq 1)$	=	Probability of observing a single count
G	=	Contamination activity (dpm)
E	=	Detector efficiency (4π)
d	=	Width of detector in direction of scan (cm)
v	=	Scan speed (cm/s)

Note: Refer to Appendix C for a complete derivation of these formulas.

Once a count is recorded and the surveyor stops, the surveyor should wait a sufficient period of time such that if the guideline level of contamination is present, then the probability of getting another count is at least 90%. This time interval can be calculated by:

$$t = \frac{13800}{CAE} \tag{5.7}$$

where

t	=	Time period for static count (s)
C	=	Contamination guideline (dpm/100 cm^2)
A	=	Detector area (cm^2)
E	=	Detector efficiency (4π)

Many portable proportional counters have background count rates on the order of 5- to 10–cpm, and a single count should not cause a surveyor to investigate further. A counting period long enough to establish that a single count indicates an elevated contamination level would be prohibitively inefficient. For these types of instruments, the surveyor usually will need to get at least two counts while passing over the source area before stopping for further investigation. Assuming this to be a valid assumption, the probability of getting two or more counts can be calculated by:

$$
\begin{aligned}
P(n>=2) &= 1 - P(n>=0) - P(n>=1) \\
&= 1 - \left(1 + \frac{(GE + B)t}{60}\right)\left(e^{-\frac{(GE + B)t}{60}}\right)
\end{aligned}
\tag{5.8}
$$

where

$P(n \geq 2)$	=	probability of getting 2 or more counts during the time interval t
$P(n=0)$	=	probability of not getting any counts during the time interval t
$P(n=1)$	=	probability of getting 1 count during the time interval t
B	=	background count rate (cpm)

All other variables are the same as for Eq. (5.6).

Appendix C provides a complete derivation of Eqs. (5.6) through (5.8) and a detailed discussion of the probability of detecting alpha surface contamination for several different variables. Several probability charts are included at the end of Appendix C for common detector sizes. Table 5.5 provides estimates of the probability of detecting 300 dpm/100 cm^2 for some commonly used alpha detectors. Results were calculated using Eq. (5.6).

Table 5.5 Probability of detecting 300 dpm/100 cm^2 of alpha activity while scanning with alpha detectors using an audible output

Detector type	Detection efficiency (cpm/dpm)	Probe dimension in direction of scan (cm)	Scan speed (cm/s)	Probability of detecting 300 dpm/100 cm^2
Proportional	0.20	5	3	80%
Proportional	0.15	15	5	90%
Scintillation	0.15	5	3	70%
Scintillation	0.15	10	3	90%

5.4 APPLICATIONS

This section describes the primary applications of instrumentation to field measurements for radiological surveys. The reader should refer to Sect. 6 for information on laboratory applications. Additional details on scanning and static radiation measurement procedures are provided in Sect. 4.

Radiological parameters that will typically be determined include total surface activities, removable surface activities, exposure rates, radionuclide concentrations in soil or other solids and liquids, and/or induced activity levels. Field measurements and laboratory analyses may be necessary to make these determinations. For certain radionuclides or radionuclide mixtures, alpha, beta, and gamma radiations may all have to be measured. In addition to assessing average radiation levels, small areas with elevated levels of residual contamination must be identified and their extent and activities determined. With so many variable applications, it is highly unlikely that any single instrument (detector and readout combination) will be capable of adequately measuring all of the radiological parameters required to demonstrate that criteria for unrestricted release have been satisfied.

Selection of instruments will require an evaluation of a number of situations or conditions. Instruments must be stable and reliable under the environmental and physical conditions where they will be used, and their physical characteristics (size and weight) must be compatible with the intended application. The instrument must be able to detect the type of radiation of interest, and must, in relation to the survey or analytical technique, be capable of measuring levels which are less than the guideline values. There are numerous commercial firms, offering a wide variety of detectors, readout devices, and detector/readout systems, appropriate for measurements described in this Manual. These vendors can provide thorough information regarding capabilities, operating characteristics, limitations, etc. for specific equipment.

When conducting a radiological survey, several basic questions must be answered:

(1) Is there residual radiological contamination present from previous uses?
(2) What is the character (qualitative and quantitative) of the residual activity?
(3) Is the average residual activity level below the established guideline value?
(4) Do small localized areas (elevated areas) of residual activity in excess of the average guideline value satisfy the established conditions (Sect. 1.3)?

For measuring direct radiation (static measurements) at low activity levels for recording purposes, the recommended instruments are:

Alpha — ZnS(Ag) scintillator with integrating capability.

Beta — Pancake GM detector with integrating capability. Both single and multiple (ganged) detector assemblies are available.

Gamma — A pressurized ionization chamber (PIC) is preferred for exposure rate measurements. Otherwise, NaI(Tl) scintillation detectors with countrate meters may be used and normalized to PIC measurements or calibrated for the energy of interest.

NOTE: Other detector types may be suitable, and possibly even necessary, for performing recordable measurements. The listed instrument types have been chosen over gas proportional types because they typically display fewer problems when exposed to variable environmental conditions such as temperature and humidity. Another problem with gas proportional detectors is that the quality of counting gases can vary from batch to batch and can ultimately affect the expected counting efficiencies. If environmental variability is not a concern and a high quality counting-gas supply is available (or these potential problems are monitored on a tight schedule during use), then gas proportional detectors can be used and will provide excellent detection capability.

Performance criteria for all instruments must allow for the detection of levels below release guideline values. A discussion of detection limits and detection levels for some typical instruments is presented in Sect. 5.2. There are certain radionuclides which, because of the types, energies, and abundances of their radiations, will be essentially impossible to measure at the current release guideline levels, under field conditions, using state-of-the-art instrumentation and techniques. Examples of such radionuclides include very low–energy, pure beta emitters such as ^{3}H and ^{63}Ni and low-energy photon emitters such as ^{55}Fe and ^{125}I. Pure alpha emitters dispersed in soil or covered with some absorbing layer will not be detectable because the alpha radiation will not penetrate through the media or covering to reach the detector. A common example of such a condition would be ^{239}Pu surface contamination, covered by paint, dust, oil, or moisture. In such circumstances the survey must rely on sampling and laboratory analysis to measure the residual activity levels.

5.5 INSTRUMENT CALIBRATION AND RESPONSE CHECK

Each instrument should be calibrated annually and response–checked with a source following calibration. Recalibration of field instruments is also required following maintenance that could affect the validity of the *a priori* calibration. The calibration interval may be longer if the manufacturer can document that the extended frequency adequately ensures the validity of the data obtained with the equipment. Calibrations should be traceable to the National Institute of Standards and Technology (NIST). Where NIST-traceable standards are not available, standards of an industry-recognized organization (e.g., the New Brunswick Laboratory for various uranium standards) may be used. The user may decide to perform calibrations following industry recognized procedures [ANSI 1978, Order DOE 5484.1 (DOE 1986c), NCRP 1978, NCRP 1985] or can choose to obtain calibration by an outside service, such as a major instrument manufacturer or a health physics services organization.

Calibration for surface activity should be performed such that a direct instrument response can be accurately converted to the 4π (total) emission rate from the source, and should be consistent with the following where necessary:

- Calibrations for point and large-area source geometries may differ, and both may be necessary if areas of activity smaller than the probe area and regions of activity larger than the probe area are present.

- Calibration should either be performed with the radionuclide of concern or appropriate correction factors developed for the radionuclide(s) present based on calibrations with nuclides emitting similar radiations to the radionuclide(s) of concern.

- Conversion factors developed during the calibration process should be for the same counting geometry to be used during the actual use of the detector.

For energy-dependent instruments being used for exposure rate measurements such as NaI, calibration for the gamma energy spectrum at a specific site may be accomplished by comparing the instrument response to that of a pressurized ionization chamber, or equivalent detector, at different locations on the site. If the energy spectrum is not homogeneous, multiple calibration factors may be required for the site.

Periodic checks of instrument response are necessary to ensure that the calibration has not changed. Following calibration, the response of each instrument to a check source is determined, and an acceptable response range is established. For analog readout (count rate) instruments, a variation of ±20% is considered acceptable (ANSI 1978). Optionally, instrumentation that integrates events and displays the total on a digital readout typically provides an acceptable average response range of ±2 to 3σ. This is achieved by performing a series of repetitive measurements (10 or more is suggested) of the check source response and determining the average and standard deviation of those measurements. From a practical standpoint, a maximum deviation of ±20% is usually adequate when compared with other uncertainties associated with the use of the equipment. The amount of uncertainty allowed in the response checks should be consistent with the level of uncertainty allowed in the final data. It is ultimately up to the site investigator to determine what level of uncertainty is acceptable.

Instrument response, meaning both the background and source–check response of the instrument, is tested and recorded at a frequency which ensures that the data collected with the equipment is reliable. For most portable radiation survey equipment, a response check should be performed at a minimum of twice daily—typically prior to beginning the day's measurements and again following the conclusion of measurements on that same day. If the instrument response does not fall within the established range, the instrument is removed from use until the reason for the deviation can be resolved and acceptable response again demonstrated. If the instrument fails the post–survey source check, then all data collected during that time period must be carefully reviewed and possibly discarded, depending on the cause of the failure. Ultimately, the frequency of response checks must be balanced with the stability of the equipment being used under field conditions and the quantity of data being collected. For example, if the instrument experiences a sudden failure during the course of the day's work due to physical harm, such as a punctured probe, then the data collected up until that point most probably may be kept even though a post-use performance check cannot be performed. Likewise, if no obvious failure occurred but the instrument failed the post-use response check, then the data collected with that instrument since the last response check should be viewed with great skepticism and possibly recollected or randomly checked with a different instrument. If recalibration is necessary, acceptable response ranges must be reestablished and documented.

5.6 RADON AND THORON DETECTION

There are three radon isotopes in nature; radon (^{222}Rn) in the ^{238}U decay chain, thoron (^{220}Rn) in the ^{232}Th chain, and actinon (^{219}Rn) in the ^{235}U chain. Radon-219 is the least abundant of these three isotopes, and because of its short half-life (3.9 s) has the least probability of emanating into the atmosphere before decaying. Radon-220, with a 55-s half-life, is somewhat more mobile; and ^{222}Rn with a 3.8-d half-life is capable of migrating through several decimeters of soil or building material before decaying into the atmosphere. Therefore, in most situations, ^{222}Rn should be the predominant airborne radon isotope.

Many techniques have been developed over the years for measuring radon (Jenkins, 1986) and radon progeny in air. As discussed in Sect. 4, radon and radon progeny emit alpha and beta particles and gamma rays. Therefore, numerous techniques can and have been developed for measuring these radionuclides based on detecting alpha particles, beta particles, or gamma rays, independently or in some combination. It is even difficult to categorize the various techniques that are presently in use. However, in this manual they have been split into four categories: sampling, integrating, continuous, and flux. Some of the procedures and instrumentation described as follows will detect ^{219}Rn and ^{220}Rn; however, they are all optimized for the quantification of ^{222}Rn.

Radon concentrations within a fixed structure can vary significantly from one section of the building to another and can fluctuate over time. If a home has a basement for instance, it is usually expected that a higher radon concentration will be found there. Likewise, an increase in the relative pressure between the soil and the inside of a structure of as little as 1% can cause an increase in the radon emanation rate from the soil into the structurem by as much as 100%. Many factors play a role in these variations, but from a practical standpoint it is only necessary to recognize that fluctuations are expected and that they should be accounted for. Long-term measurement periods are required to determine a true mean concentration inside a structure and to account for the fluctuations.

Two analytical end points are of interest when performing radon measurements. The first and most commonly used is radon concentration, which is stated in terms of activity per unit volume (pCi/L or Bq/m^3). Although this terminology is consistent with most Federal guidance values, it only infers the potential dose equivalent associated with the radon.

The second analytical end point is the radon progeny working level. Radon progeny carry a net positive valence and usually attach to charged aerosols in the air very quickly following creation. Since most aerosol particles carry an electrical charge and are relatively massive ($\geq 0.1\ \mu$m), they are capable of attaching to the surfaces of the lung. Essentially all dose from radon is associated with alpha decays from radon progeny attached to aerosols that have attached to lung tissue. If an investigator is interested in accurately determining the potential dose associated with radon in the air of a room, the radon progeny concentration must be determined.

Radon progeny concentrations are usually reported in units of working levels (WL), where one working level is equal to the potential alpha energy associated with the radon progeny in secular equilibrium with 100 pCi/L of radon. This potential alpha energy is 1.28×10^5 MeV/L. Given a known breathing rate and lung attachment probability, the expected mean lung dose from exposure to a known working level of radon daughters can be calculated.

Radon progeny will not usually be found in secular equilibrium with radon indoors due to plating out of the charged aerosols onto walls, furniture, etc. The ratio of radon progeny activity to radon activity usually ranges from 0.2 to as high as 0.8 indoors. If only the radon concentration has been measured and it is not practical to measure the progeny concentrations, then general practice is to assume a progeny to radon equilibrium ratio of 0.5 for indoor areas. This allows one to estimate the expected dose associated with a given radon concentration.

In general, the following generic guidelines should be followed when performing radon measurements during DOE–funded site investigations:

- The radon measurement method used must be well understood and documented.
- Long-term measurements are required in order to determine the true mean radon concentration.

- The impact of variable environmental conditions on the measurement process should be accounted for when necessary. Consideration should be given to both the air collection process and to the counting system.
- The background response of the detection system must be accounted for.
- If the analyte of interest is working level, then the radon progeny concentrations should be evaluated when possible. If this is not practical, then the progeny concentrations should be assumed to be 50% of the radon concentration.

The following provides a general overview of radon sampling and measurement concepts. The intent of this section is to provide a generic description of common methods and terminology.

5.6.1 Sampling Methods

5.6.1.1 Grab samples

• Radon

A grab sample for radon or radon progeny is one that is taken over a brief period of time (15 min or less) and for which the analysis is performed shortly thereafter (within a few hours). The main advantage of using a grab-sampling method for measurement of radon or radon progeny in air is that a result can be determined quickly. Also, the equipment used is usually simple and inexpensive compared to other methods. The disadvantage of grab-sampling methods is that the result is only valid for one instant in time. Radon and radon progeny concentrations can vary considerably with time, sometimes over several orders of magnitude. For health protection purposes, one is interested in long-term average concentrations. The results from grab-sampling may or may not be representative of a long-term average concentration. However, grab-sampling techniques are useful for a quick characterization of a house or building, for locating a source of radon, for cross-checking other techniques, for interlaboratory comparisons, etc.

Quite simply stated, a radon sample is taken by collecting air in some type of container and then determining the radon concentration in the collected air. The container can be a device such as a metal cylinder, which has been previously evacuated. In that case, the sample is collected by opening a valve on the container and allowing air to enter until the pressures are equalized. Alternatively, the container can be a device, such as a Tedlar bag or a flow-through scintillation cell, which is filled by pumping air into or through it. In any case, the air is collected over a relatively short period of time and then analyzed for concentration of radon.

• Radon progeny

Another way to perform a grab sample is to collect radon progeny. All radon progeny grab samples are based on pumping air through a filter and analyzing the radon progeny collected. The analysis can be based on counting alpha particles, beta particles, gamma rays or some combination, such as alpha/beta counting (Perdue 1978). Usually, however, the analysis is performed using alpha counting. The discussion here will be limited to techniques using alpha-particle counting.

5.6.1.2 Charcoal canisters

The measurement of radon flux can be achieved by adsorption onto charcoal (Countess, 1976). A canister of charcoal is sealed onto the surface of interest during a collection period of typically two or three days. The canister is then removed from the surface, sealed to prevent escape of the radon, and analyzed using gamma spectrometry techniques. From the collected activity of radon in the canister, the rate of entry into the canister is determined and hence the radon flux.

This method has proved to be reliable for measuring radon flux in normal environmental situations. However, care should be taken if an extremely large source of radon is measured with this method. The collection time should be chosen carefully to avoid saturating the canister with radon. If saturation is approached, the charcoal loses its ability to absorb the radon and the collection rate then decreases. Also, if saturation is approached, the activity of radon in the canister will be so large that it will be impossible to measure with a gamma spectrometry system. Even transporting and handling of a canister that is saturated with radon can be a problem due to the dose rate from the gamma rays being emitted. One would rarely encounter a source of radon that is so large that this would become a problem; however, it should be recognized as a potential problem.

5.6.1.3 Radon collection by adsorption onto charcoal

A method that has come into popular use rather recently is collection of radon by adsorption onto charcoal. Charcoal is placed in a container, such as a canister or a bag, and is sealed until ready for use. The sample is collected simply by placing the container in the room to be sampled, and opening the container so the charcoal is exposed to the room air. Radon in the ambient air then passively adsorbs onto the charcoal. After the sampling period, typically from three to seven days, the container is sealed and taken to a laboratory where the radon content is determined using gamma-ray spectrometry. This is done by placing the container on a NaI(Tl) detector system including a multichannel pulse-height analyzer. Because radon decay products are being detected, at least four hours should elapse between the end of the sampling period and the beginning of the count to ensure that the decay products are in equilibrium with the radon.

In spite of the difficulties with calibrating charcoal devices, this method is becoming very popular for several reasons. The charcoal devices are very inexpensive. They can be heated to drive off the radon and then reused. Sufficient lapse of time before reuse will also allow decay of the radon progeny. Charcoal canisters are simple to deploy. The analysis is straightforward and uses equipment that is common to most radiological laboratories and is not prohibitively expensive.

5.6.2 Direct Measurement of Radon

Direct radon measurement is generally performed by gathering radon into a chamber and measuring ionizations produced. A variety of methods have been developed, each making use of the same fundamental mechanics but employing different measurement processes. The first step is to get the radon into a chamber without collecting any daughter products from the ambient air. A filter is normally used to capture charged aerosols while allowing the noble radon gas to pass through. Passive monitors rely on convective air currents to move air through the chamber while active monitors use some type of air pump system for the air exchange method.

Once inside the chamber, the radon decays by alpha emission to form ^{218}Po which usually carries a positive charge. Some monitor types collect these ionic molecules and subsequently measure the alpha particles emitted by the radon daughters. Other monitor types measure the ionization produced by the daughters in the air directly by collecting the ionization electrons. Simple systems measure the cumulative radon during the exposure period based on the total alpha decays that occur. More complicated systems actually measure the individual pulse height distributions of the alpha and / or beta radiation emissions and derive the radon plus daughters isotopic concentration in the air volume.

Care must be taken to accurately calibrate a system and to understand the effects of humidity, temperature, and atmospheric pressure on the system. These conditions create little adverse effect on some systems, while others can be greatly influenced.

• Integrating Methods

With integrating methods, measurements are made over a period of days, weeks, or months, and the device is subsequently read by an appropriate device for the detector media used. The most common detectors used are thermoluminescent dosimeters (TLDs), teflon electrets, and alpha–track plastics. Short-term fluctuations are averaged out, thus making the measurement representative of a time–weighted average concentration. Integrating methods result in average values, therefore, there is no way to determine the fluctuations of the radon concentration over time. Successive short-term measurements can be used in place of single long-term measurements to gain better insight into the time dependence of the radon concentration.

• Continuous Methods

Devices that measure direct radon concentrations over successive time increments are generally called continuous radon monitors. These systems are more complex than integrating devices in that they must measure the radon concentration and log the results to a data recording device on a real-time basis. Continuous radon measurement devices normally allow the noble radon to pass through a filter into a detection chamber where the radon decays, and the radon and resulting progeny are measured. The most common detectors used for real-time measurements are ion chambers, solid state surface barrier detectors, and ZnS(Ag) scintillation detectors.

Continuous methods offer the advantage of providing successive short-term results over long periods of time. This allows the investigator to determine not only the average radon concentration, but also to analyze the fluctuations in the values over time. Some more complicated systems also measure the relative humidity and temperature at the measurement location, and log the values along with the radon concentrations to the data logging device. This allows the investigator to make adjustments, if necessary, to the resulting data prior to reporting the results.

5.6.3 Radon Progeny Measurements

Radon progeny measurements are performed by collecting charged aerosols onto filter paper and subsequently counting the filter for attached progeny. Some systems pump air through a filter and then count the filter inside the pump for alpha and / or beta emissions. A simpler but more labor-intensive method is to collect a sample using an air sampling pump, and then count the filter in a stand–alone alpha and/or beta counting system. The measurement system may make use of any number of different techniques ranging from full alpha and beta spectrometric analysis of the filters to simply counting the filter for gross alpha and/or beta emissions.

When performing gross counts, the assumption is usually made that the only radioisotopes in the air are due to radon and its progeny. This error, which is usually very small, can be essentially eliminated when performing manual sampling and analysis by performing a follow-up analysis of the filters at an hour or more post-analysis. This value can then be used as a background value for the air.

Time is a critical element in radon progeny measurements. Given any initial equilibrium condition for the progeny isotopes, an investigator must be able to correlate the sampling and measurement technique back to the true concentration values. When collecting radon progeny, the buildup of total activity on the filter increases linearly until the activity approaches a saturation point. At this point, the decay rate of the progeny atoms on the filter is equal to the collection rate of progeny atoms. One must account for this when interpreting analysis results.

It is important to note that the number of charged aerosol particles in the air can affect the results for these kinds of measurements. If the number of particles is low, as is possible when humidity is very low and the room is very clean, then the progeny are not attached and will most likely pass through the filter. This isn't a problem if the same conditions always exist in the room; however, the calculated dose would underestimate the dose that would be received under conditions of higher humidity or dust concentration with the same radon progeny concentration.

5.6.4 Measurement of Radon Flux

Sometimes it is desirable to characterize the source of radon in terms of the rate at which radon is emanating from a surface, such as soil, uranium mill tailings, or concrete. One such method is briefly described here.

Flux cans of various sizes, shapes, and designs have been used for measuring radon flux but the procedure followed is basically the same. The can is sealed onto the surface to be studied, and samples of air are taken from the can periodically. Since the area of the surface covered by the can is well defined, the radon flux [in units of pCi/(m^2-sec), for example] can be calculated.

5.7 SPECIAL EQUIPMENT

Various specialized systems have been developed that can aid in the performance of radiological surveys. These range from specially designed quick radiation scanning systems to commercialized global positioning systems (GPS). When considering the use of a large-area or quick radiation-scanning system, the expected detection sensitivity for the survey must be matched to the quality of data needed.

5.7.1 Mobile Systems (Vehicle–Based)

The need to identify anomalous radiation levels that may go undetected in the absence of extraordinary effort and cost is one factor that has resulted in the development of an assortment of specialized equipment. Depending on the application, motorized vehicle-based detector systems have been developed and used in conjunction with a variety of large-area radiological surveys. These types of systems have primarily proven to be useful for preliminary screening of areas which had a low or unknown probability of being contaminated. Once identified, a more thorough manual survey is usually needed.

5.7.2 Positioning Systems

In general, before any surface radiological survey can be performed, a measurement grid system must be established. A variety of practical and versatile global positioning systems (GPS) based on radio signals tracked from satellite beacons in space are available to aid in recording precise and retrievable location data. Such devices are good for locating reference points in terms of latitude and longitude. The reference point may then be translated into established State, local, or other grids.

A GPS receiver installed in a known, surveyed location can broadcast accurate readings in the 2- to 10-m range in real time to other GPS receivers. Although this increases accuracy, such systems will suffer precision in areas where trees, buildings, or other obstacles block the effective "view" of orbiting satellites. The most practical use of GPS in radiological investigations is to use the system for establishing a zero point for local gridding. This allows one to tie the survey grid to a State, local, or other grid system. The survey grid can then be laid using conventional transit methods.

Other devices that may be useful in performing radiological surveys are systems that track both the position and output of radiation detectors. One such system is the ultrasonic ranging and data system (USRADS, Nyquist and Blair, 1991). It tracks a surveyor's path while performing a survey and provides documentation of both location and magnitude of instrument response at 1–s intervals during the survey. Current commercially available versions of this particular system use one surveyor and track the position of the surveyor, not the position of the actual detector.

5.7.3 Ground-Penetrating Radar and Magnetometry

Ground-penetrating radar and/or magnetometers can be useful at waste or survey sites for determining the location, composition, and approximate depth of buried metallic objects, and to indicate buried materials when conducting subsurface investigations (Geo-Centers, Inc., 1980). Drums, tanks, well heads, and even trucks can be located.

Subsurface radar detection systems have been the object of study for over a decade by both military and environmental agencies for locating and identifying buried or submerged objects otherwise not detectable. The instrumentation generates a pulse train of electromagnetic radiation that is propagated with material-dependent attenuation through a given medium (the earth) until reflected by a material or boundary of different dielectric properties. The time between transmission and event recorded indicates time, distance, and/or composition of reflecting material.

Magnetometers are instruments that measure magnetic fields, and more importantly, small disturbances in the earth's magnetic field. Gamma units are used in reporting measurement of magnetic fields. Magnetometers are portable, have a sensitivity of 0.1 gamma (the earth's average magnetic field is 50,000 gammas) and can be operated quickly and easily. One useful application is locating buried drums. At a typical hazardous waste site, where buried drums and tanks are being searched for, the operator would carry the sensor in a backpack. Disturbances of the earth's magnetic field caused by such metallic objects as drums, tanks, and trucks can be used to determine the location of the object and to estimate its volume.

5.7.4 Aerial Radiological Surveys

Low–altitude aerial radiological surveys* are designed to encompass large areas and may be useful in:

- providing data to assist in the identification of radioactive contaminants and their corresponding concentrations and spatial distributions; and
- characterizing the nature, extent, and impact of contamination.

The measurement sensitivity and data processing procedures provide total area coverage and a detailed definition of the extent of gamma-producing isotopes for a specific area. The gamma-radiation spectral data are processed to provide a qualitative and quantitative analysis of the radionuclides in the survey area. Helicopter flights establish a grid pattern (e.g., east–west) of parallel lines approximately 61 m (200 ft) above the ground surface.

The survey consists of airborne measurements of natural and man–made gamma radiation from the terrain surface. These measurements allow for the determination of terrestrial spatial distribution of isotopic concentrations and equivalent gamma exposure rates (e.g., ^{60}Co, ^{234m}Pa, and ^{137}Cs). The results are reported as isopleths for the isotopes and are usually superimposed on scaled maps of the area.

*Source: A. E. Fritzsche, *An Aerial Radiological Survey of the White Oak Creek Floodplain*, Oak Ridge Reservation, Oak Ridge, Tennessee, Remote Sensing Laboratory, EGG–10282–1136 (June 1987).